

A COMPARISON OF
THREE METHODS OF
SEWAGE DISINFECTION
BASED ON
FISH EXPOSURES DOWNSTREAM
OF THE
TILLSONBURG (ONTARIO) STP



Ministry
of the
Environment

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BASED ON
FISH EXPOSURES DOWNSTREAM
OF THE TILLSONBURG (ONTARIO) STP

by

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ACKNOWLEDGEMENTS

We appreciate the long hours and extra efforts of Doug Whittman and Peter Wilson, Ministry of the Environment, Laboratory Services and Applied Research Branch, in providing on-site chemical analyses.

Credit for the design and installation of the ultra violet light disinfection system in the Tillsonburg Sewage Treatment Plant go to Elliot Whitby and Jan Maarschalkerweerd of Trojan Environmental Products, London, Ontario; while representatives of Great Lakes Chemicals of Lafayette, Indiana in conjunction with Lawrason's Chemicals, London provided and operated the sodium bromide/chlorination method of disinfection in the Tillsonburg S.T.P.

The authors would also like to extend their deep appreciation to G. Craig, J. Pagel, D. Veal and K. Nicholls for their constructive criticism in reviewing this report and to Donna Donnelly, Joanne Bélanger and the Acid Rain Co-ordination's Office for the typing of the manuscript.

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INTRODUCTION

Regulatory agencies in Canada and the U.S. have been concerned with the toxic effects of sewage effluent chlorination on receiving water biota for a number of years. (Basch, 1972; Cairns and Conn, 1974; Inniss and Curry, 1981; Flood et al, 1984). As part of the ongoing assessment of alternatives to chlorination, fish exposures were undertaken in Big Otter Creek, downstream of the Tillsonburg sewage treatment plant (STP), during the fall of 1982.

Previous work at Tillsonburg in 1980 indicated that the STP plume was lethal to fish due to excessive chlorine residuals in the effluent (Huber et al, 1981). Other field studies involving STP wastes have also shown similar results (Esvelt et al, 1973; Servizi and Martens, 1974; Tsai, 1973; Inniss and Curry, 1981; etc.). Cairns and Conn (1974) found chlorinated sewage to be acutely lethal to rainbow trout fingerlings, wherein the 96-h LC50 in terms of total residual chlorine (TRC), averaged 0.04 mg/L (N=12). In regards to the protection of aquatic life based on sub-lethal bioassay studies, Brungs (1973) recommended that chlorine not exceed 0.002 mg/L. The concentrations of chlorine discharged from the Tillsonburg plant ranged from 0.24 to 1.4 mg/L over a 24-h period during the 1980 study (Huber et al, 1981).

The objective of this work was to compare effluent quality of a chlorinated sewage waste, in regard to fish lethality in the receiving water, with that of:

- 1) a sodium bromide/chlorination process, and
- 2) an ultraviolet (UV) light irradiation procedure.

Hypobromous acid, the active ingredient in the NaBr/Chlorine treatment, is an effective disinfectant (Mills, 1975; Keswick, 1977) with less stability in the environment than its' chlorine counterpart, and as such, is likely to cause less of an environmental impact (Ward and De Graeve, 1978). UV treatment is also a good disinfection technique and was used in a few water treatment plants in the U.S. during the 1920's. Future applications may include the treatment of storm water and sewage effluents, for pilot plant studies have demonstrated that UV treatment is a viable disinfection alternative to chlorination (Ho and Bohm, 1981; Oliver and Carey, 1976); while simultaneous laboratory bioassays showed UV-irradiated effluents to be non toxic to rainbow trout (Oliver and Carey, 1976).

This study was part of a project to assess several aspects of effluent and receiving water quality by comparing disinfection methodologies in a functioning sewage treatment plant. The other studies involved:

- 1) an assessment of the in-plant disinfection efficiencies. (Palmateer et al, 1983; Cook, 1983);
- 2) a delineation of the STP effluent plume downstream of the STP. (Huber et al, 1983).

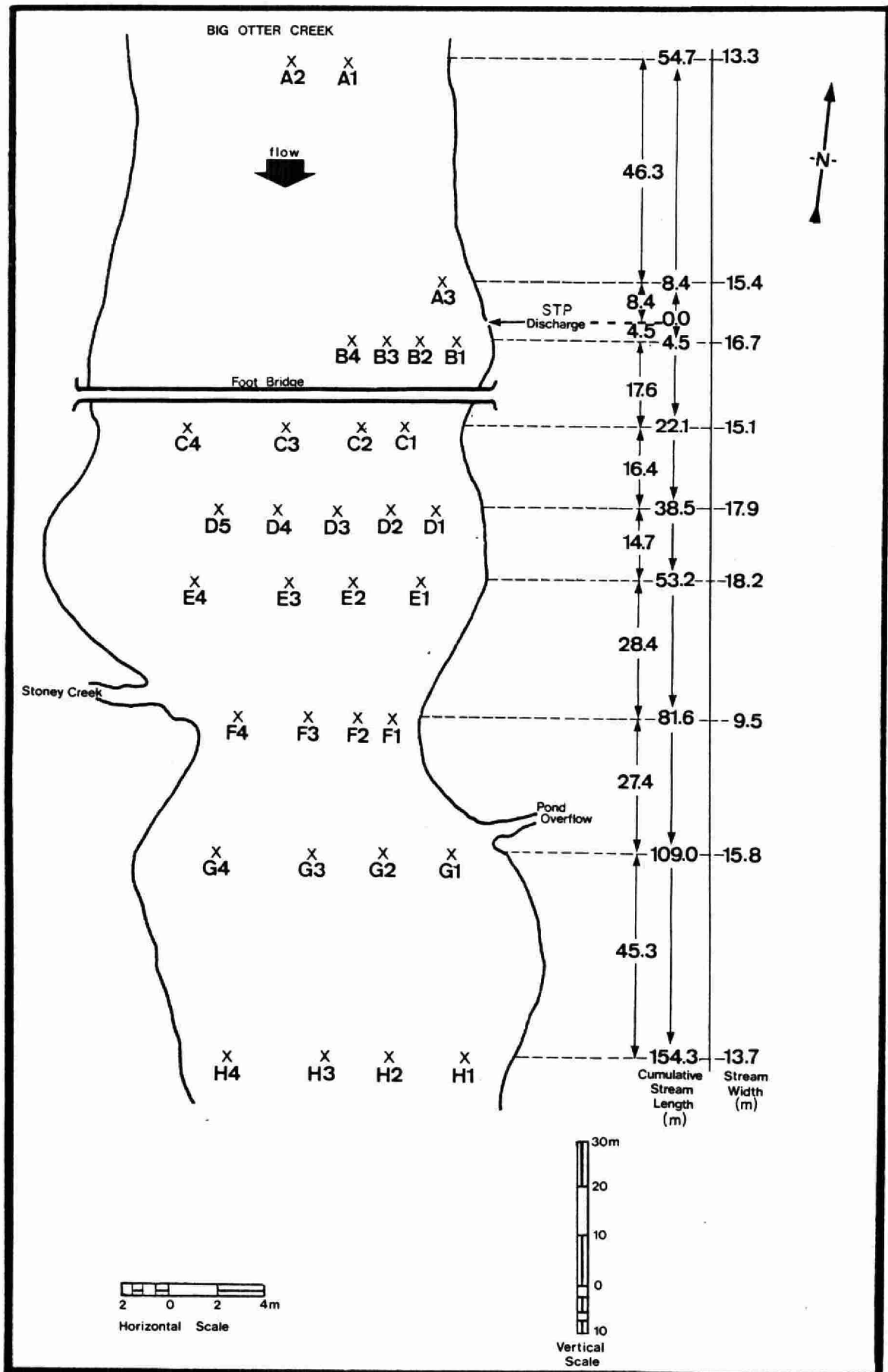
Study Site and Treatment Descriptions

The Tillsonburg STP services a population of 12,000 in a farming area, 30 Km southeast of London, Ontario. It is a conventional activated sludge STP which discharges 4.6×10^3 m³ of effluent/day to a stretch of Big Otter Creek in Tillsonburg's Coronation Park. The creek contains resident populations of small mouth bass, rainbow trout and accommodates spawning runs of suckers and pike in the spring. Furthermore, it is considered one of the most important salmonid streams in southwestern Ontario, for it receives a high degree of fishing pressure during the fall run of Coho salmon. The study site is shown in figure 1.

During March of 1981, a UV disinfection system was put into operation at the Tillsonburg STP. The present facility consists of dual chlorine contact chambers, dual UV sterilization systems of two units each in series, settling tanks and settling tank effluent channels. This system allows for a combined or individualized evaluation of UV and chlorine disinfection (Whitby et al, 1982; Palmateer et al, 1983).

Bromine disinfection was undertaken at Tillsonburg by adding a 25% sodium bromide solution (NaBr) to chlorine in the chlorine injection system of the plant to produce the hypobromous acid disinfectant. The addition was undertaken with a metering pump and minor plumbing alterations to the existing facilities (Cook, 1983).

FIGURE 1 : Study Site in Big Otter Creek , Tillsonburg .



METHODS

Test Format

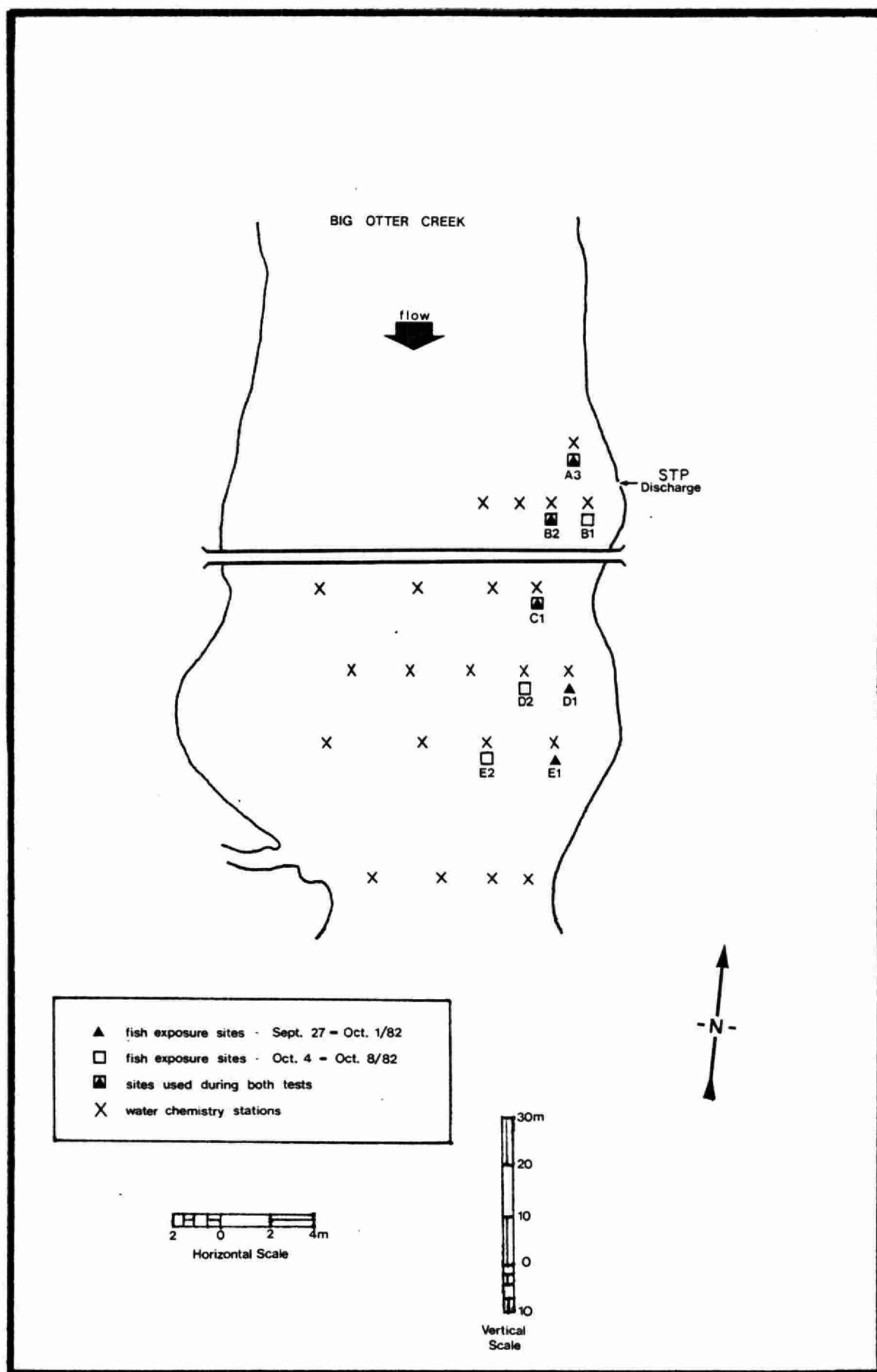
Four separate 48-h exposures of fish were undertaken downstream of the STP outfall. Individual treatments were tested on a Monday-Wednesday and Wednesday-Friday basis, for two weeks commencing September 27/82. The sequence of treatments 1-4 during the study were: 1) UV light irradiation (UV-1), 2) chlorination 3) the sodium bromide/chlorination method and 4) a repeat UV treatment (UV-2).

Test Sites

Fish were exposed in cages at up to five sites downstream of the STP outfall and in one upstream control cage. Each exposure site corresponded to one of many chemical sampling stations present in an overall grid system. The fish cages were situated in a linear progression downstream at distances of 4.5 (B1,B2), 22 (D1, D2), 38.5 (D1,D2) and 53m (E1,E2) from the outfall. The specific exposure sites for week 1 (Sept. 27th to Oct. 1st) and week 2 (Oct. 4th to Oct. 8th) are illustrated in figure 2.

The closest exposure site to the outfall was set at B2, based on a pre-test stream measurement of chlorine undertaken Sept. 26th and visual observations of the

FIGURE 2 : Fish Exposure Cage Locations.



effluent foam. Chemical analyses during the first week of exposures indicated that IRC values at B1 exceeded those of B2 and therefore fish cages were located at both sites during the second exposure week.

For week 2 of the study, cage locations were changed from sites D1 and E1 to D2 and E2 respectively, due to a critical drop in water levels; as well as a resultant shift in the plume path. No fish were exposed beyond site E (approximately 53 m. downstream of the discharge) due to excessively fast stream flows (50-60 cm/sec) during two storm events.

Fish

Yearling rainbow trout (Salmo gairdneri) were obtained from a local hatchery, situated on the upper reaches of Otter Creek. The mean ($\bar{x} \pm \text{S.D.}$) weight and length of fish used in the study were 45.8 ± 18.5 g and 15.5 ± 2.7 cm, respectively.

Prior to use, the fish were held in aerated, spring-fed ponds at the hatchery, exclusive of chlorine or chlorine residuals and with a water temperature of 15°C. The study was undertaken in September in order for stream temperatures at the exposure sites to correspond to the optimal thermal range for rainbow trout and to coincide with the hatchery water temperatures. The fish were transported to the test

site in polyethylene bags containing hatchery water and an oxygen headspace. The acclimation of fish for each test involved a 24-hour upstream holding period with no feeding prior to or during the exposure. Water temperature for the holding site was in the 12-15°C range throughout the study period. The fish not used in the test were fed twice daily, ad libitum, and held in separate cages.

Cages

The cages in this study were developed by Munro and Pawson (Pawson, et al, 1983). They were constructed with a 1.9 cm ($\frac{3}{4}$ ") polyvinylchloride pipe frame and a nylon-net bag, 0.6 cm ($\frac{1}{4}$ ") mesh. The cages were one metre triangles with a depth of 0.5 m and a volume of 0.4 m³. Access to the cage bag was through the top with closure maintained by way of a draw string.

Screening was erected around the test cages to protect the fish from a local great blue heron. The exclosures were constructed of "chicken wire" attached to 1x2 inch wood frames. The screening was kept above the water level so as to eliminate the possibility of zinc leaching from the galvanized wire.

Test Procedure

Fifty fish were exposed at each site with an exception for the chlorination portion of the study. In that case,

only 30 fish were exposed at each site, due to a reduction of the fish stock through vandalism.

Each test commenced in the early afternoon with a random placement of fish into the exposure cages. Mortality was recorded hourly over the first 10 hours of the test and within intervals of less than 8 hours thereafter. Dead fish were removed upon observation. A fish was considered dead when, after mild prodding, there was no visible respiration or other movement.

Current speed of the creek was measured daily at the front and out through the back of the cages, along with water depths at the inside three corners of the cages. Dissolved oxygen and temperature measurements were also performed daily in the cages. Exposures were terminated after 48 hours. At the conclusion of the tests, final observations were made and all control fish were sacrificed, weighed and measured (for total length).

Chemical Analyses

Water samples were collected from the exposure sites once daily for metals and general water quality parameters. Total residual chlorine, ammonia-nitrogen, pH and conductivity were measured on-site as often as possible each day. Samples of the initial ten collection runs for IRC were also analyzed for phenolics; and since sulphur springs

were predominant throughout the area, a set of samples were collected on the initial day to measure sulphide levels (which were not detectable).

Residual halogens were measured using the amperometric titration method with phenylarsine oxide, and were expressed as TRC unless otherwise noted. This methodology could not discriminate between chlorine and bromine in the NaBr/chlorination portion of the study, and therefore the quantification of each component was impossible. Consequently, for that part of the study, the TRC levels are representative values if only chlorine was present; while the levels expressed in terms of bromine would be $2.25 \times$ the TRC value (i.e. a ratio of their atomic weights).

RESULTS AND DISCUSSION

Chlorine Treatment

Total residual chlorine levels downstream of the STP outfall ranged from 100-300 ug/L during the initial 5 hours of the fish exposure (Table 1). At those levels, threshold mortalities were observed at all exposure sites up to 53 m downstream, within two hours. The estimated time to 50% lethality (LT50) occurred two hours thereafter in the case of fish exposed 22 and 38.5 m downstream, with a maximum of 6.4 hours required at the 53 m site. All fish exposed downstream of the STP outfall were dead within 24 hours while no control mortalities were observed over the 48-h test period.

Merkens (1958) undertook toxicity studies of chlorine/ammonia solutions and found the free chlorine component to be much more toxic to rainbow trout than the chloramines. Several random samples of the Tillsonburg effluent were analyzed for TRC and its chlorine components. From those data, it appears that the proportion of free chlorine relative to TRC was quite small (10% maximum). In the Merkens (1958) test solution which best describes the chlorine composition of Tillsonburg's effluent, an LT50 of 5 hours was produced for the fish exposed to 200 ug TRC/L. That result corresponds very closely to the findings of this

Table 1: Chlorine levels at the various fish exposure sites and related fish lethality during the first few hours of the chlorination treatment of STP wastes at Tillsonburg

Fish Exposure Sites	Meters downstream from discharge	Chlorine levels (ug/L) @ test times		% mortality at test time										LT50 (h)
		1.5 h	4 h	1	2	3	4	Hours		7	8	9	10	
B2	4.5	109	210	0	3	13	27	47	57	70	70	73	73	5.3
C1	22	218	165*	0	3	17	50	67	67	83	83	87	90	4
D1	38.5	292	222**	0	7	23	50	67	83	83	83	100	-	4
E1	53	230	184	0	3	10	27	37	43	60	60	67	70	6.4
control		0	0	0	0	0	0	0	0	0	0	0	0	non lethal

Estimated values

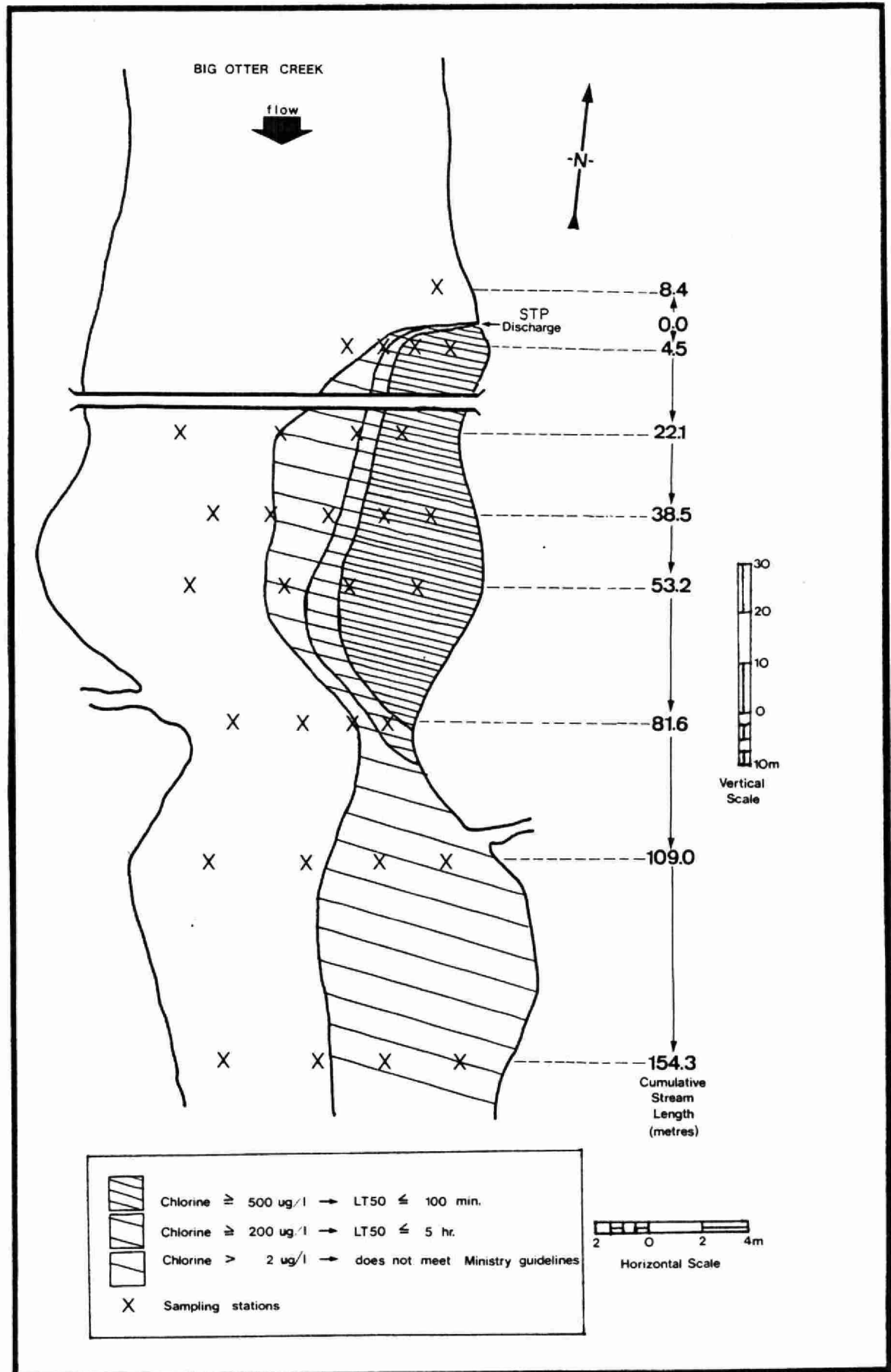
* calculated from the linear regression relationship of chlorine values at C1 vs E1 ($r^2=.92$; $p>0.05$; $N=7$)

** calculated from the linear regression relationship of chlorine values at D1 vs E1 ($r^2=.99$; $p>0.05$; $N=7$)

study. Merkens also demonstrated that TRC levels of 500 ug/L would produce an LT50 in approximately 1 2/3 hours (100 minutes). TRC levels discharged from the Tillsonburg plant were in excess of that value during the morning of Oct. 1st and therefore may have produced an equally dramatic result had a test been undertaken at that time. Figure 3 identifies the concentration profile of the effluent plume during that period, and outlines potential zones of biological impact on the creek in regard to rainbow trout lethality and the Ministry guideline for the protection of all aquatic life.

In ecological terms, a zone of passage does exist whereby fish can avoid chlorine residuals from the STP by migrating up the western side of the creek (Figure 3). Huber et al (1981) came to a similar conclusion in an earlier study. Nevertheless, it should be realized that a chlorinated effluent has the potential to produce detrimental effects on the biota even if such a zone of passage exists. For example, Sprague and Drury (1969) found that rainbow trout preferred certain concentrations of chlorine known to be lethal to them, while Servizi and Martens (1974) observed a situation in which trout did not avoid lethal concentrations of chlorinated sewage when free to do so, and died as a result. Furthermore, even short-term exposures to high chlorine concentrations can produce physiological damage to fish (Grothe and Eaton, 1975; Bass et al, 1977). During a previous study at the

FIGURE 3 : Potential Zones of Impact due to Chlorine.



Stratford STP, indigenous fish were observed under stress in an STP plume several times over a week-long period, and dead suckers were found downstream of the plant outfall (Flood et al, 1984). No fish were observed in the plume during the chlorine exposure at Tillsonburg.

Although chlorine is the principal toxic component in this waste, other constituents which may have caused a minor portion of the lethality are ammonia from the STP effluent, and elevated levels of aluminum and iron from sources upstream of the STP, which may have interacted with the effluent.

The aluminum concentrations were comparable throughout the exposure sites and ranged from 0.5-0.7 mg/L during the chlorination portion of the study. The pH levels at the control station were significantly higher ($x=8.32$) than those at the test sites ($\max.x=7.76$). Freeman and Everhart (1974) demonstrated that 0.52 mg Al/L would not produce an LC50 to rainbow trout over 45 days when tested at a pH of 7.0 or 8.0 and a hardness level of 10-20 mg/L (as CaCO_3). Therefore, similar aluminum levels found at Tillsonburg would have likely had little effect in regard to acute toxicity especially at the Big Otter Creek hardness level in the range of from 250-270 mg/L (as CaCO_3).

The highest recorded level of iron during the chlorination study was 0.41 mg Fe/L (pH-7.39; hardness-260 mg/L as CaCO_3); which is four-fold less than the 96-h LC50

for brook trout, as cited by Decker and Menendez (1974). Therefore under the exposure conditions at Tillsonburg, iron levels would not likely have been lethal within a 48-hour period.

The highest un-ionized ammonia level at any site was calculated to be .007 mg/L. That value is less than 4% of the lowest reported LC50 for rainbow trout of 0.2 mg/L (Liebmann, 1960).

UV Treatments

Two separate exposures of fish were undertaken downstream of the STP effluent discharge. The initial exposure (UV-1) produced 48-h mortality levels in the effluent plume of 14, 10, 4 and 6% at distances downstream of 4.5, 22, 38.5 and 53 m, respectively. A storm event during the first day of the exposure caused a portion of the untreated sewage to bypass the plant and discharge along with the final effluent. This problem was rectified for the rest of UV-1 and for all subsequent exposures.

For the second test (UV-2), two cages were exposed along the transect, 4.5 m downstream from the discharge (B1,B2); and the 38.5 and 53 m cages were moved from sites D1 to D2 and E1 to E2, due to a dramatic drop in water levels prior to the exposure. No fish mortalities were observed at any of the test sites during the UV-2 test.

TRC levels were not detected at any site during either of the tests. Other potential toxicants were present in the form of elevated aluminum, iron and ammonia levels.

Aluminum levels did not exceed 0.8 mg/L during UV-1 while maximum levels of 1.0 and 1.2 mg/L occurred at one UV-2 site (the highest recorded values during the overall study). Similarly the maximum iron value of 1.16 mg/L at a UV-1 site was exceeded by the mean value of 1.37 and a maximum of 3.05 mg/L at one site during the UV-2 test (the latter value constitutes the highest recorded during the overall study). In both cases, the test exposures experiencing the highest aluminum and iron levels were non lethal. Although ammonia levels were elevated in the effluent plume during the start-up of the exposure, all values were calculated to be an order of magnitude less than the most sensitive lethal concentration reported for rainbow trout in the literature (Liebmann, 1960). Therefore ammonia, exclusive of that combined to produce chloramines, had little direct effect on the acute toxicity observed during the UV-1 test. The likely cause of the lethality was the untreated waste that was found to have bypassed the STP treatment system during this portion of the study; although no specific chemical parameter, virus or bacteriological constituent can be identified as the toxic agent.

Sodium Bromide/Chlorination Treatment

Threshold fish mortality was observed at the 4.5 m station (B1) within 2 hours, while the time to 50% lethality occurred in less than 4 hours. During that portion of the study, halogen measurements ranged from 15-18 ug/L, measured as chlorine, or 33-41 ug/L as bromine. TRC levels which produced an equivalent effect (LT50) during the chlorination study were approximately an order of magnitude greater (100-300 ug chlorine/L) at the same distance downstream of the discharge. These findings indicate that brominated wastes are more toxic, although significantly lower levels are discharged as a byproduct of a satisfactory (Cook, 1983) disinfection process.

An explanation for the difference in the lethal concentrations of these halogens and levels required for effluent disinfection is the biocidal reactivity of the bromine versus chlorine residuals. Bromamines have a disinfection efficiency which is superior to chloramines (Mills, 1975). Therefore, since the disinfectant in the chlorination study was present mainly in the less reactive chloramine form (90% of TRC), then it can be expected that a significantly lower concentration of bromine relative to chlorine was required to produce a similar lethal response; even if the principal bromine component was present entirely as bromamines.

Unlike the dramatic effects observed for station B1, lethality at the 22 m station (C1) remained steady with 18% mortality in the first 24 hours of the test and 24% during the following 24-48 h period. The corresponding halogen levels in terms of bromine were 25 ± 8 ug Br/L (N=5) and 55 ± 22 ug Br/L (N=3), respectively. Complete mortality due to higher halogen levels during the 24-28 h test period may not have occurred prior to the test completion. Six fish died within the last 2 hours of the test while three others were exhibiting various degrees of stress, which included, trouble maintaining equilibrium, impaired ability to maintain their position in the current and a darker color relative to the other fish.

At the 38.5 m downstream station (D2), there was 18% fish mortality over the 48-h exposure and no signs of stress observed in the survivors. Data for the 53 m station were not included due to interference with the test fish by a great blue heron.

The results of the study demonstrate a marked decrease in lethality at progressive distances downstream of the SIP discharge. Lethality levels of 100, 42 and 18% were recorded at the 4.5, 22 and 38.5 m stations respectively.

Of the contaminants which were considered, only a halogen can account for the lethality during the sodium bromide/chlorination treatment of the waste. The highest

level of unionized ammonia detected during this portion of the study (.009 mg/L) is two orders of magnitude less than values cited in the literature as acutely lethal. Also, the levels of aluminum and iron measured in the effluent plume were lower than levels found to be non lethal in the UV study.

A Comparison of Disinfection Treatments

Each of the three treatment methods as undertaken during this study produced satisfactory effluent disinfection (Palmateer et al, 1982; Cook, 1983). However, there were differences in the degree of fish lethality at the exposure sites downstream of the STP discharge (Table 2). Chlorination of the waste produced the most lethal condition throughout the length of the effluent plume. Complete mortality was recorded within 24 hours as far as 53 m downstream from the effluent outfall. The sodium bromide/chlorination treatment was less toxic beyond the 4.5 m station than chlorination-only; nevertheless, the plume was lethal with fish mortality levels of 42 and 18% at the 22 and 38.5 m sites, respectively.

The most satisfactory results occurred for the second UV light disinfection test (UV-2). No fish mortality occurred in a 48-hour period, at stations identical to those during the sodium bromide/chlorination study. In the

Table 2: Fish mortality results for each disinfection treatment after a 48-hour exposure

Disinfection Test	Fish mortality results at the exposure sites Downstream from STP outfall								Upstream
	4.5m		22m	38.5m		53m		8.4m	
	B1	B2	C1	D1	D2	E1	E2	A3	
UV-1	— ¹	14%	10%	4%	—	6%	—	2% ²	
Chlorination	—	100% @24 h	100% @24 h	100% @24 h	—	100% @24 h	—	0	
Na/Br/Chlorination	100% @18 h	2%	42%	—	18%	—	*	0	
UV-2	0	0	0	—	0	—	0	0	

¹— denotes no cage present

² the 1 of 50 fish which died was very small and partially eaten

* no mortality up until 10 hours into the test-thereafter blue heron attacks on fish in this cage and hence mortality results disregarded. There was no evidence of interference with any of the other test fish.

initial UV test in which exposure stations were identical to those for the chlorine treatment, lethality was observed. The cause is believed to be due to the extraneous source of untreated sewage which bypassed the treatment plant during a storm event. Nevertheless even with that added input, the test result was still more acceptable than results of the other treatment methods, in regard to the protection of the receiving water biota.

The C1 exposure site, 22 m downstream from the outfall, was a nearshore station used in all four treatment studies. It received the highest concentration of sewage effluent relative to the other 22 m transect stations and the conductivity relationship between sites C1 and C2 was not significantly different throughout the study ($p > .05$). At the same time, differences in lethality did occur at site C1 due to the various disinfection treatments; with complete mortality in the chlorine study, no mortality during one UV study (4% in the other), and 42% mortality for the sodium bromide/chlorination treatment.

In summary, UV irradiation was found to be the most acceptable form of disinfection at the Tillsonburg STP; while chlorination was found to be less than acceptable, based on fish mortality downstream of the outfall.

The results of the sodium bromide/chlorination treatment were also an improvement on a chlorination-only

CONCLUSIONS

1. A zone of lethality in Big Otter Creek extends at least 53 m downstream of the Tillsonburg STP during current disinfection practices at that plant.
2. The bromine disinfection process produced lethality downstream of the STP. Significant fish mortality occurred in the plume at the 22 m cage, while a threshold of mortality was present at least 38.5 m downstream of the discharge.
3. A full delineation of the zone of lethality during the sodium bromine/chlorination treatment was incomplete due to a cessation of the test prior to the stabilization of the test population responses.
4. The two disinfection alternatives, UV light and *the sodium bromide/* chlorination treatment, were less lethal than chlorination-only based on mortality results for site C-1 in each test.
5. In regard to fish lethality, the UV light treatment of the effluent was the most environmentally acceptable means of treatment of the three methods tested in the study.

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